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WHOLE BODY COOLING WITH PROTECTIVE CLOTHING DURING COLD WATER IMMERSION

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WHOLE BODY COOLING WITH PROTECTIVE CLOTHING DURING COLD WATER IMMERSION

by

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Abstract

Heat losses during water immersion have been evaluated for nude and clothed heated copper manikins (Goldman et al., 1966), and for nude men (Goldman and Gee, 1973). Data are now presented for subjects immersed in still, cold water (28°C and 20°C), nude (.14 clo) and in 6.25 mm vinyl (.43 clo), 9.4 mm polyurethane (.61 clo), and 6.25 mm neoprene (.76 clo) wet suits. Metabolic rates (M), EKG, heat flow (discs at 5 sites), rectal (T_{re}) and 10 skin temperatures ($\bar{T}_s$) were obtained in air, then during a 60 min immersion period, and for 20 min thereafter. The T_{re} at 60 min for the nude, and all clothed conditions, taken together with the decreases in M associated with increased insulation, suggest that the effect of insulation is to conserve the metabolic energy cost associated with maintaining a given level of T_{re}.

Index terms: Hypothermia, water immersion, insulation

Introduction

Based on descriptions of the heat transfer characteristics of the human body (Hardy and Soderstrom, 1938; Stolwijk and Hardy, 1965; Stolwijk, 1969), a major effort in the description of thermoregulation has been a systems analysis of physiologic responses to environmental stimuli (Wyndham and Atkins, 1960; Crosbie et al., 1961; Wissler, 1963). As a result of increasing human exposures to cold water environments (Molnar, 1946; Golden and Rivers, 1975), these general analyses have been extended to include whole body immersion (Goldman et al., 1966; Craig and Dvorak, 1966; Gee and Craig, 1970; Miller and Seagrave, 1974). Control and prediction of immersion heat losses and human tolerance to cold water have also received much attention (Goldman et al., 1966; Beckman, 1968; Beckman et al., 1965, 1966; Bullard, 1970; Witherspoon and Goldman, 1970; Hall, 1972; Hayward et al., 1974).

Heat losses during water immersion have been evaluated for nude and clothed heated copper manikins (Goldman et al., 1966), and for nude men (Goldman and Gee 1973) as part of a program for modeling human heat losses. In a continuation of that effort, new data are now presented for human subjects, immersed in "still," cold water at 20^{o} and 28^{o}C, both nude (i.e., estimated as a .14 clo insulating still water film from copper manikin measurements, although our human studies suggest a 0.05 clo value (Goldman 1980)) and clothed in a range of wet suits: 6.25 mm vinyl (.43 clo), 9.4 mm polyurethane (.61 clo) and 6.25 mm neoprene (.76 clo).

Methods

Ten male volunteers (Table 1) were immersed at a depth of 0.3 meters for 60 minutes. Each subject volunteered to be immersed on 8 separate occasions, in the nude and in each of 3 wet suits, at water temperatures (T_w) of 20^{o} and 28^{o}C. Rectal temperature (T_{re}) was monitored with a YSI thermistor inserted to a depth of 10 cm. Ten copper constantan thermocouples and five Keithly RFD heat flow discs were placed over the torso, extremities and forehead for calculation of mean weighted skin temperature ($\bar{T}_s$) and of mean weighted surface heat losses (MWSHL). A 3 lead EKG was positioned. Air samples were collected in a Tissot (chain compensated) gasometer and oxygen and carbon dioxide concentrations were measured with Beckman E_2 and LB_1 gas analysers, respectively. Metabolic rates (M) were calculated according to Weir. Height, weight and skinfolds were obtained for calculation of body surface area and subcutaneous fat.

Subjects were asked to lie supine on a cot suspended above a 34,000 liter immersion pool for 6 minutes while baseline temperature, heat flow data, and expired air samples for calculation of metabolic rates were obtained. Similar data were then collected for 60 minutes while subjects were immersed, and during the 20 minutes after immersion. Metabolic and heat flow data were collected at 6 minute intervals, temperature data at 1.4 minute intervals.

Results

The mean weighted skin temperature response for all subjects for each suit and water temperature are presented in Figure 1. Mean fall in skin temperature, starting at an overall mean value of 33^{o}C, was 5^{o}C after 60 minutes of nude immersion in 28^{o} water, compared to 11^{o}C in 20^{o} water; 90% of these decreases occurred in the first three minutes. Nude subjects in 20^{o} water experienced intermittent cold induced

vasodilatation, as evidenced by rhythmic transient rises in skin temperature. When wet suits were worn, the fall after 60 minutes immersion was 1 to 2°C in 28° water, and 5 to 7°C in 20° water; while 60% (20°C) to 90% (28°C) of the drop still occurred in the first three minutes, the time patterns were quite different, with some rewarming appearing in the 28° water and a more gradual fall toward the final 60 minute values in the 20° water.

For both the 20° and 28° water temperatures, subject skin temperatures separated out in the same relative order as suit clo values; the higher the clo value, the higher the skin temperature. However, the responses of subjects wearing vinyl and polyurethane suits were more similar than would be anticipated from the insulation values of these suits (vinyl = 0.43 clo; polyurethane = 0.61). This can be attributed to a relatively poorer fit of the polyurethane suit which tended to reduce its insulation in water, thus equalizing the clo values. Subjects wearing the neoprene suits showed a high pre-immersion skin temperature. This can be attributed to the high insulation value and consistent good fit of the neoprene suits.

Rectal temperatures are presented in Figure 2. No ranking of temperature relative to clo insulation is evident during the 60 minutes of immersion at either water temperature; however, in 28° water the greater insulation of the neoprene suit begins to be apparent after 40 minutes. The drop in rectal temperature for all nude and clothing conditions after 1 hour ranged from 0.4 to 0.6°C for both water temperatures.

Rectal temperatures during the 18-minute post-immersion period generally continued to decline for all conditions in both 20 and 28° water, reflecting the heat lost from the core to rewarm the skin; however, the rate of decline decreased.

Mean metabolic heat production after 60 minutes in 28° water (Fig. 3) increased by 30 W/m^2 from pre-immersion values for nude subjects, but were essentially unchanged when the wet suits were worn. Nude subjects in 20° water experienced a mean increase in heat production of 130 W/m^2 over the 60-minute immersion period. This increase was associated with sustained heavy shivering. In 20° water, subject responses were similar when wearing the vinyl and polyurethane suits, demonstrating mean increases in heat production of 45 W/m^2. Those clad in neoprene showed a mean increase of only 15 W/m^2. The diminished rise in M associated with increased insulation, when considered with the rectal temperature at 60 min for the nude and all clothed conditions, suggests that an important effect of wet suit insulation is to conserve the metabolic energy cost associated with maintaining a given level of rectal temperature.

A four variable analysis of variance design was used to evaluate temperature and metabolic data. While a highly significant triple interaction ($P < .001$) indicated that trends across time for skin and rectal temperatures and metabolic rates were not the same for each clothing condition, it appears that the 28° water was not sufficiently stressful, while the 20° water was too stressful, to clearly discriminate between wet suits over this range of insulation; i.e. these temperatures, as forcing functions, fell on either side of the appropriate temperature range to discriminate between these suits (Goldman, 1980).

Mean weighted surface heat loss (Fig. 4), as measured by 3 to 5 heat flow discs, demonstrated an initial peak immediately upon immersion, suggesting dissipation of tissue heat content; this was followed by a decline toward a steady state, representative of core to surface heat flow, as compensatory heat conservation mechanisms came into play. Nude subjects in 28° water experienced an initial maximum heat loss rate of 220 W/m^2; this declined after about 20 minutes and plateaued at 130 W/m^2 after one hour of immersion. The rate of heat loss for nude subjects in 20° water was a maximum of 380

W/m^2 on immersion and this dropped to 220 W/m^2 by the end of the hour immersion period. The range of heat loss for subjects in the suits after 60 minutes of immersion in 20^o water was 140 to 170 W/m^2. As with rectal temperatures, the heat loss responses for suited subjects tended to overlap.

Discussion

Data have been presented for four clothing conditions and two water temperatures which describe basic temperature, metabolic, and surface heat flow responses during cold water immersion. The data suggest that the effect of insulation is more to conserve the metabolic energy cost associated with maintaining a given level of rectal temperature than to alter the trends in rectal temperature per se, at least during immersion of not more than one hour. A rectal temperature predictive equation:

$$(T_{re} = 37.2 - (t-15)(0.0785-0.0034T_w)$$

has been developed (Hayward et al., 1974) for men immersed without insulation at water temperatures less than 23^oC. When applied to the response of our insulated men in 20^oC water, Hayward's equation, predicted a $0.47^oC/hr$ decrease in T_{re} temperature which is consistent with our data.

Since respiratory distress and exhaustion have been demonstrated during cold water immersion (Golden, 1975; Keatinge, 1972) the observation that metabolic rate, rather than rectal temperature, appears to be conserved with added insulation suggests that a limiting factor in some individuals may be exhaustion and drowning rather than hypothermia per se. The corollary observation is that insulated suits may conserve metabolic rate, preclude exhaustion and allow survival until core temperature drops to levels incompatible with life.

Mathematical Modeling

The problems of whole body cooling, especially those of immersion cooling with its attendant protective garments, have received much attention (Goldman, et al., (1966); Beckman, et al., (1966); Beckman, (1968); Gee and Craig, (1970); Bullard and Rapp, (1970); Rawlins and Tauber, (1971)). More recently, there has been a concerted effort at this Institute (USARIEM) to develop both empirical (J. Witherspoon, 1969–72) and theoretical (J. Stewart, 1973-74) mathematical descriptions of whole body cooling. The general whole body cooling equation developed by Goldman and used by Witherspoon and Goldman (1970) has been emphasized because of its immediate practical use in relating forcing functions to insulation, and in describing the magnitude and time course of changes in metabolic rate, skin and rectal temperature. While this whole body cooling equation is of special import in immersion cooling, where it may be critical to predict aircrew and diver temperature response as a function of time, water temperature, and garment insulation, it is also directly applicable to air cooling and, indeed, is an extension of Van Dilla's equation for extremity cooling (cf. Newburgh, 1949).

The particular form suggested initially for this whole body cooling equation is:

Eq 1) Skin: $Ts_t = T_w + 0.18\, q\, (clo_{ext}) + (T_{s_i} - T_w + .18\, q\, (clo_{ext}))\, \bar{e}^{t/}a_s$

Eq 2) Rectal: $T_{re_t} = T_w + 0.18\, q\, (clo_{ext}) + .18\, (.88\, M\text{-}q)\, (\; clo_{circ} + clo_{fat})$

$$+ (T_{re_i} - T_w + 0.18\, q\, (clo_{ext}))\, \bar{e}^{t/}a_{re}$$

where:

Ts_t = skin temperature at a time t

Ts_i = initial skin temperature

T_{re_t} = rectal temperature at a time t

T_{re_i} = initial rectal temperature

T_w = water temperature

t = time (hrs)

clo_{ext} = external boundary layer + any garment insulation (clo)

clo_{fat} = fat insulation (clo)

M = metabolic rate (Watt/m^2)

q = circulatory heat flow core to skin (Watt/m^2)

clo_{circ} = circulatory insulation (clo)

a_s = time constant for skin temperature to reach 64% of final value; $2a_s$ produces 95% of final value.

a_{re} = time constant for rectal temperature, as for skin

Basic verification of this equation was carried out with a copper manikin. Verification on human subjects to date has only been attempted for nude male subjects (Goldman and Gee, 1973).

Equations No. 1 and 2 can be broken down into four smaller descriptive equations:

Eq 3) $Ts_{eq} = T_w + 0.18\, q\, clo_{ext}$

Eq 4) $T_{st} = T_{seq} + (T_{s_i} - T_{seq})\, e^{-t/as}$

Eq 5) $T_{re_{eq}} = T_{seq} + 0.18(.88M-q)(clo_{fat} + Clo_{cir})$

Eq 6) $T_{re_t} = T_{re_{eq}} + (T_{re_i} - T_{r_{eq}})\, e^{-t/}a_{re}$

where Ts_{eq} and Tre_{eq} represent final equilibrium values for skin and rectal temperatures respectively.

The underlying assumption of these equations is that the skin and rectal temperatures follow single exponential decay patterns. For the level of cold stress applied (T_w) within the 1-hr time constraint this assumption is not true. If rectal temperatures could be followed below $35^{\circ}C$ a single exponential would perhaps be a reasonable model. However, within the short immersion period, and our T_{re} safety limit of $35^{\circ}C$, any exponential decay nature of these curves is obscured by the increase, with time, in the metabolic response to cold stimulus. T_{re} does not approach equilibrium, nor does $\bar{T}_s$ for the subjects when clothed.

Working with best estimates of T_{seq} does allow calculated estimates to be made for core to skin heat flow (q). These are presented in Fig. 5. Unfortunately, when tested in Eq 6 for the nude man in a $20^{\circ}C$ water condition, using individual values from Table 1, calculated estimates of T_{re} approached $50^{\circ}C$. Therefore q is apparently a complex variable which cannot be adequately defined or empirically described with the model chosen.

However, the single exponential descriptive equation for $\bar{T}_s$ (Eq 2) proved adequate, if the initial 2-4 minutes of data were ignored. Figures 6 through 10 present the single exponential descriptions of $20^{\circ}C$ exposures in the nude, in vinyl, polyurethane, and neoprene wet suits and in $28^{\circ}C$ water in the nude.

The attempts to model the metabolic responses as a function of time met with difficulties equal to that of modeling $\bar{T}_s$. As can be seen in Fig. 3, metabolic rate as a function of time displays an initial peak followed by a drop and then a slow rise to a plateau just prior to withdrawal from the water. The initial peak has been linked loosely with skin temperature changes over the first 10 minutes of immersion (Timbal et al., 1976). A continuous descriptive equation which adequately dealt with this initial peak could not be developed within the conceptual restraints of equations 1 through 6. Linear discontinuous approximations of these responses are presented in Figures 11 through 14.

It is apparent then that, within the very appropriate safety restraints for our immersion studies, we will be forced to develop more complex descriptions of the irregular responses of $\bar{T}_s$, T_{re}, and M which occur in the first hour of immersion. If data from hypothermic surgery patients or accident victims with severe stress for prolonged times were available, perhaps this portion of the curve could be de-emphasized and single exponential descriptions would be appropriate. However, this is not the case and Equations 1 through 6 may have to be abandoned.

Physical modelling of the situation suggests that a double exponential descriptive equation would be more appropriate in an attempt to develop an empirical description of the $\bar{T}_s$ responses of immersion subjects; the $\bar{T}_s$ calculated values from such an equation are plotted with accompanying raw data for one subject in Fig. 15. The fit, though not perfect, seems a reasonable approximation and suggests that this approach should be pursued. The complete mathematical description of the interaction between M, T_{re}, $\bar{T}_s$, and time seems beyond the limits of available data even if the single exponential approach is abandoned. Insight into possible empirical approaches can be gained, however. A more careful examination of T_{re} vs. Time (Fig. 16) suggests that understanding and describing T_{re} as a function of time is dependent upon understanding the 'transient plateau' or rise in T_{re} following immersion. It follows that a rise in M should cause an increase in T_{re}; however, the rise in T_{re} is perhaps more likely to be due to the massive vasoconstriction which occurs upon immersion. It is the same as wrapping a heated cylinder with insulation (suddenly) - the internal temperature must rise in order to establish the temperature gradient necessary to re-establish the previous rate of heat transfer. Metabolic heat

production (M) for the various clothing conditions versus T_{re} are presented in Figure 17 for 1 subject. It is reasonably evident from this display that at each set of water temperature and clothing insulation, T_{re} is the determining factor for M although shivering is usually considered to be correlated with skin temperature. The measured T_s may be different from the actual tissue temperature below the skin surface where the receptors are located since the T_s measurements were affected by the water temperature to quite a large degree and the "actual T_s" vs. time probably lagged a bit behind the measured T_s dependence of M on T_{re}. This includes the initial spike in the M vs. time plot which Timbal, et al. (1976) attributed to dT_s/dt. We feel this initial M spike is equally probably due to the initial rapid drop in T_{re} (Fig. 16) rather than to the sensory response to T_s or dT_s/dt since most of these changes occur in the first 0-3 minutes of immersion and the M spike apparently does not occur until 6-18 minutes of immersion have elapsed. However, continuous T_s, T_{re}, O_2 and CO_2 recordings are needed to fully document this.

Further discussion will be limited to Nude 28°C, Vinyl 20°C and Nude 20°C conditions since, as can be seen in Fig. 17, these provide a well spaced sampling of the response range. The responses of M to changes in rectal temperature can be described by a sigmoid curve. For purposes of this discussion Perl's equation was utilized (Fig. 18). A Gaussian, Gompertz or any of a variety of similar equations would also have been adequate. The determining factors of the equation are F, D (slope), E (T_{re} at onset of metabolic rate response) and M_{max}. Interestingly, only E and M_{max} vary between water and clothing conditions. This suggests that since water temperature and clothing determine the rate of change in T_{re}, both E and M_{max} are also functions of clo ext and dT_{re}/dt, while F and D are functions of clo_{fat}, and clo_{circ}. The potential for arriving at a generalization of this concept is lost, however, since there are too few subjects and the subjects utilized fall at the extremes of body style. While subjects 22, 21 and 8 are quite lean, and show dramatic responses in T_s and T_{re}, (Figs 15,16,17,18) and M (Tables 2,3,4), subjects 1 and 4 are mild to modestly obese and show only limited responses (Tables 5,6). This can be readily seen from the plot of nude metabolic responses for the 5 subjects (Fig. 19) as a function of surface area; % body fat and skinfold give similar results. In the absence of data on subjects of intermediate body morphology there is no way to develop a continuous description of D,E,F and M_{max} and a subsequent description of the interaction between M, T_{re} and dT_{re}/dt. This becomes particularly apparent when the M vs T_{re} plots of subject 22 (16% body fat) and subject 4 (23% body fat) are compared (Figures 18 and 20).

In summary, without good clinical data from hypothermic patients and/or victims of accidental immersion, we are restricted to the initial portions of the T_{re}, T_s, and M immersion curves. In one sense, this is appropriate, since it is in this short span before $T_{re} \leq 35^{\circ}$ that the victim can maintain homeothermic defences. If restricted to these portions of the curve we must deal with metabolic and/or vasomotor based deflections of T_{re} vs. time. In this regard M is apparently a function of T_{re} and dT_{re}/dt. To determine and describe this relation with any degree of certainty, continuous recordings of expired air O_2 and CO_2, ventilation, and temperature responses must be made in a number of subjects who adequately cover the range of body fat between 13 and 23%, or a much more sophisticated model must be developed.

Table 1
Anthropomorphic Data

Skinfolds in mm

	Ss#2	Ss#1	Ss#3	Ss#4	Ss#20	Ss#19	Ss#22	Ss#21	Ss#7	Ss#8
Suprail.	13.4	25.3	10.8	23.4	18.4	6.6	7.9	9.5	7.7	6.5
MidAx	6.2	18.4	6.9	1.53	9.6	5.7	7.8	7.9	5.4	5.2
Chest	7.7	18.8	5.3	12.3	8.5	5.6	11.8	7.2	5.6	5.8
Biceps	5.4	7.8	4.3	5.9	5.0	4.2	4.3	4.5	3.8	3.6
Thigh	13.3	17.4	9.9	21.4	9.8	9.6	18.7	13.3	10.9	10.6
MidCalf	9.0	11.0	6.0	11.2	10.4	4.2	9.8	8.4	9.6	4.4
Abd	8.8	27.7	7.9	23.5	13.6	8.0	11.6	9.6	8.9	6.8
ForeArm	6.0	6.2	5.2	6.8	4.0	3.7	3.7	5.2	3.5	1.1
Triceps	10.4	10.3	5.6	17.5	10.3	6.4	11.5	9.0	6.6	6.5
SubScap	10.1	19.4	11.5	18.4	13.0	9.3	13.1	10.8	7.4	7.6
Bifold Ave.	9.0	16.2	7.3	9.8	10.2	6.3	10.0	8.5	6.9	5.8
Ave.Thckns	4.5	8.1	3.6	4.9	5.1	3.1	5.0	4.3	3.5	2.9

Body Density (Durnin and Rahaman) = 1.1610-.06321 log $(S_1+S_4+S_9+S_{10})$

Body Fat (Siri) = $\left(\frac{4.950}{B.D.} - 4.5\right) \times 100\%$

Thermal conductance: 1 clo = 6.45 watt/m^2 °C = 5.55 kcal/m^2hr°C

Thermal conductance: Fat = 14.4 kcal/m^2hr°C per cm

Clo/cm Fat = 2.23

	Ss#2	Ss#1	Ss#3	Ss#4	Ss#20	Ss#19	Ss#22	Ss#21	Ss#7	Ss#8
% BF	15.10	22.62	14.49	23.09	18.97	12.17	16.09	15.06	11.71	11.09
FtClo	1.01	1.81	.87	1.10	1.14	.71	1.12	.96	.78	.65
Ht cm	176.80	185.60	183.30	178.00	171.00	168.90	174.50	170.30	176.20	176.20
Wt kg	70.22	96.22	72.42	95.55	77.52	63.51	72.25	69.13	63.40	66.33
SA m^2	1.87	2.23	1.91	2.15	1.89	1.71	1.88	1.81	1.78	1.82

Table 2
Subject 22

Metabolic rate (M), Skin (T_s) and Rectal (T_r) temperature responses in 28°C water/nude and 20°C water both nude and clothed in a vinyl wet suit.

	28°C, Nude			20°C, Vinyl			20°C, Nude		
Time (min)	T_s °C	T_r °C	M W/m^2	T_s °C	T_r °C	M W/m^2	T_s °C	T_r °C	M W/m^2
0	32.84	37.46	34.82	32.74	37.46	45.97	32.21	37.60	42.66
6	29.36	37.29	43.66	29.16	37.32	67.83	21.59	37.42	123.93
12	29.00	37.26	42.80	28.16	37.29	63.14	20.89	37.44	147.98
18	28.94	37.19	45.56	27.70	37.30	58.24	20.91	37.46	144.39
24	28.92	37.04	41.15	27.32	37.26	65.89	21.64	37.46	118.56
30	28.87	36.99	47.20	26.96	37.24	81.79	20.97	37.44	128.53
36	28.86	36.88	54.42	26.64	37.16	76.99	20.74	37.42	134.55
42	28.65	36.77	55.83	26.40	37.13	84.79	20.70	37.35	133.64
48	28.75	36.48	64.34	26.32	37.08	90.48	20.76	37.23	144.75
54	28.59	36.54	70.89	26.21	37.06	83.03	20.74	37.17	146.98
60	28.65	36.63	68.24	26.04	37.04	85.97	20.74	37.04	156.45

Table 3
Subject 21

Metabolic rate (M), Skin (T_s) and Rectal (T_r) temperature responses in 28°C water/nude and 20°C water both nude and clothed in a vinyl wet suit.

	28°C, Nude			20°C, Vinyl			20°C, Nude		
Time (min)	T_s °C	T_r °C	M W/m^2	T_s °C	T_r °C	M W/m^2	T_s °C	T_r °C	M W/m^2
0	33.43	37.54	35.22	33.56	37.73	52.41	31.92	37.74	52.92
6	29.20	37.37	43.44	25.95	37.63	73.15	21.75	37.65	137.25
12	28.87	37.33	58.24	23.80	37.66	57.86	21.30	37.69	127.35
18	28.61	37.33	45.19	27.86	37.68	63.81	21.14	37.66	128.18
24	28.62	37.28	55.13	27.78	37.66	60.11	21.21	37.59	151.41
30	28.49	37.24	57.53	27.38	37.63	70.12	21.05	37.46	180.03
36	28.43	37.20	66.18	27.27	37.57	75.35	21.07	37.37	200.54
42	28.40	37.13	63.87	27.15	37.48	86.78	21.11	37.24	198.40
48	28.34	37.07	55.05	27.01	37.41	97.02	21.05	37.08	212.43
54	28.39	36.99	69.25	26.82	37.34	109.44	21.00	37.01	233.16
60	28.36	36.92	74.33	26.77	37.30	106.15	20.98	36.93	215.47

Table 4
Subject 8

Metabolic rate (M), Skin (T_s) and Rectal (T_r) temperature responses in 28°C water/nude and 20°C water both nude and clothed in a vinyl wet suit.

Time (min)	28°C, Nude			20°C, Vinyl			20°C, Nude		
	T_s °C	T_r °C	M W/m^2	T_s °C	T_r °C	M W/m^2	T_s °C	T_r °C	M W/m^2
0	33.20	37.29	50.66	33.73	37.55	43.15	33.06	37.63	44.51
6	29.10	37.20	63.67	28.25	37.44	51.62	22.77	37.55	109.02
12	28.88	37.16	77.62	28.12	37.35	54.71	21.86	37.47	175.80
18	28.64	37.08	86.73	27.67	37.29	63.07	22.04	37.33	219.90
24	28.55	36.98	97.31	27.30	37.16	76.02	21.92	37.25	217.36
30	28.63	36.93	100.76	26.95	37.04	88.75	21.54	37.11	195.10
36	28.61	36.85	81.24	26.43	36.90	99.84	21.40	36.99	222.46
42	28.57	36.77	99.53	26.34	36.77	110.31	21.71	36.89	201.34
48	28.56	36.72	115.98	26.48	36.67	78.57	21.26	36.73	227.97
54	28.56	36.68	100.60	26.04	36.51	160.65	21.14	36.64	231.98
60	28.26	36.64	92.50	25.72	36.44	82.64	21.23	36.57	229.53

Table 5
Subject 1

Metabolic rate (M), Skin ($\bar{T}_s$) and Rectal (T_r) temperature responses in 28°C water/nude and 20°C water both nude and clothed in a vinyl wet suit.

	28°C, Nude			20°C, Vinyl			20°C, Nude		
Time (min)	$\bar{T}_s$ °C	T_r °C	M W/m^2	$\bar{T}_s$ °C	T_r °C	M W/m^2	$\bar{T}_s$ °C	T_r °C	M W/m^2
0	32.92	37.37	44.63	32.36	37.97	41.84	33.33	37.83	42.80
6	29.49	37.34	80.86	29.28	37.88	43.03	22.78	37.79	86.18
12	28.70	37.41	58.67	28.14	37.87	44.65	22.26	37.82	64.55
18	28.63	37.47	53.66	27.55	37.87	43.59	21.63	37.79	83.62
24	28.50	37.47	62.91	27.22	37.86	40.25	21.45	37.77	68.95
30	28.58	37.44	62.55	26.79	37.83	41.03	21.29	37.72	77.34
36	28.48	37.43	60.37	26.47	37.81	42.60	21.19	37.64	77.45
42	28.44	37.41	62.26	26.21	37.79	43.26	21.22	37.57	102.63
48	28.45	37.38	57.64	26.04	37.77	42.74	20.46	37.51	86.00
54	28.36	37.33	64.10	25.79	37.75	35.96	21.22	37.46	92.55
60	27.89	37.34	52.95	25.69	37.70	44.52	21.18	37.41	96.46

Table 6
Subject 4

Metabolic rate (M), Skin (T_s) and Rectal (T_r) temperature responses in 28°C water/nude and 20°C water both nude and clothed in a vinyl wet suit.

	28°C, Nude			20°C, Vinyl			20°C, Nude		
Time (min)	T_s °C	T_r °C	M W/m^2	T_s °C	T_r °C	M W/m^2	T_s °C	T_r °C	M W/m^2
0	33.93	37.82	46.38	33.67	38.00	50.88	32.49	37.59	54.30
6	29.33	37.78	41.89	30.72	37.86	43.69	22.48	37.54	64.18
12	28.94	37.72	52.73	29.15	37.73	54.14	21.77	37.56	57.86
18	28.90	37.64	48.97	28.12	37.41	49.04	21.56	37.60	51.75
24	28.89	37.47	46.79	27.39	37.35	41.79	21.42	37.61	59.64
30	28.82	37.30	42.53	26.92	37.25	45.18	21.22	37.61	54.34
36	28.76	37.08	50.90	26.44	37.15	47.43	21.21	37.57	59.95
42	28.82	36.95	46.06	26.24	37.06	54.92	21.10	37.55	54.51
48	28.77	36.86	39.94	26.02	36.99	51.80	20.99	37.51	67.06
54	28.72	36.81	41.69	26.42	36.94	52.68	20.94	37.43	73.52
60	28.70	36.75	39.60	26.94	36.90	50.89	20.88	37.34	76.38

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MEAN WEIGHTED SKIN TEMPERATURES (MWST) DURING WHOLE BODY IMMERSION; NUDE, AND WEARING 1/4" VINYL, 3/8" POLYURETHANE AND 1/4" NEOPRENE WETSUITS.

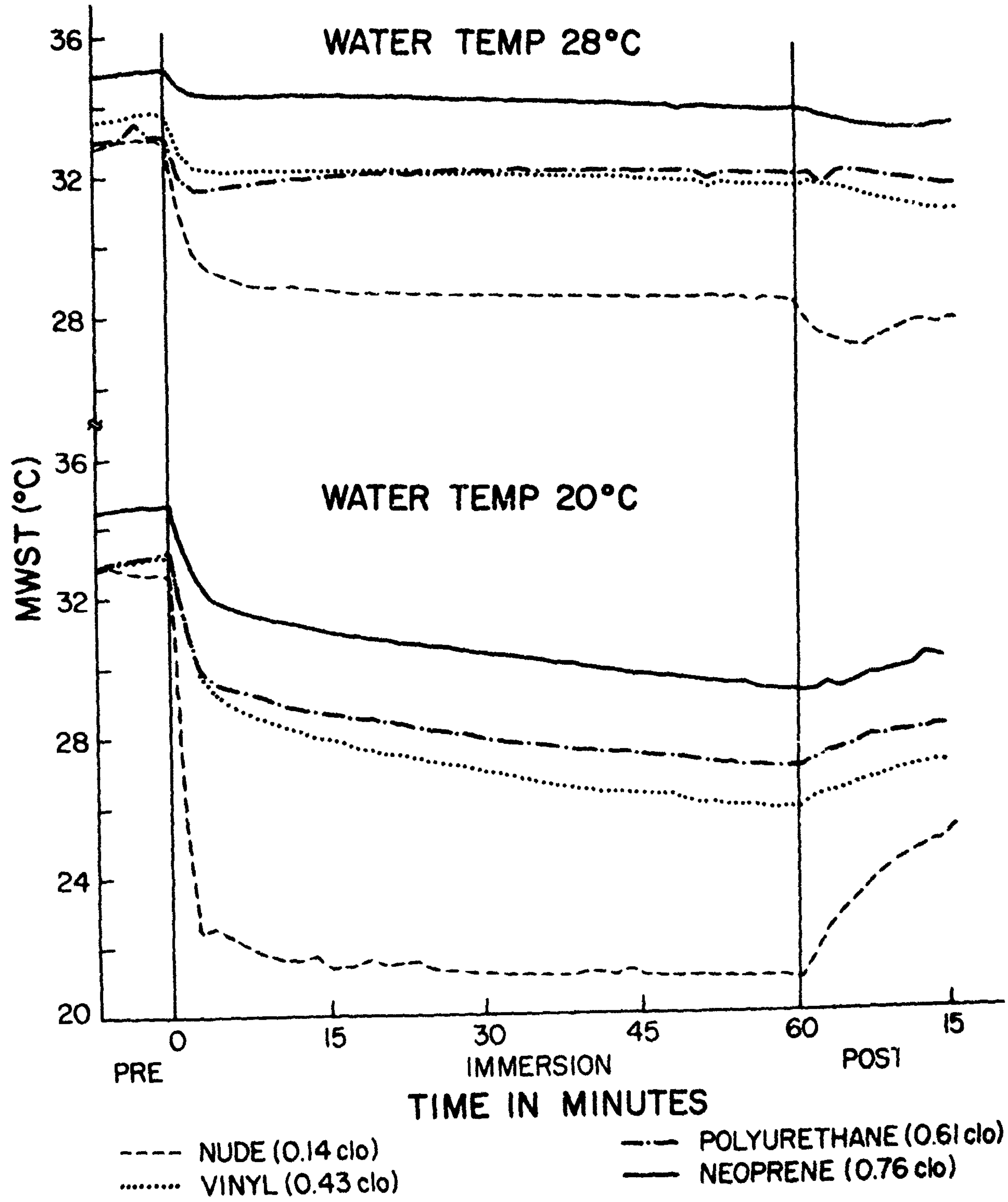

Figure 1. Mean Weighted Skin Temperatures (MWST) During Whole Body Immersion; Nude, And Wearing 1/4" Vinyl, 3/8" Polyurethane And 1/4" Neoprene Wetsuits.

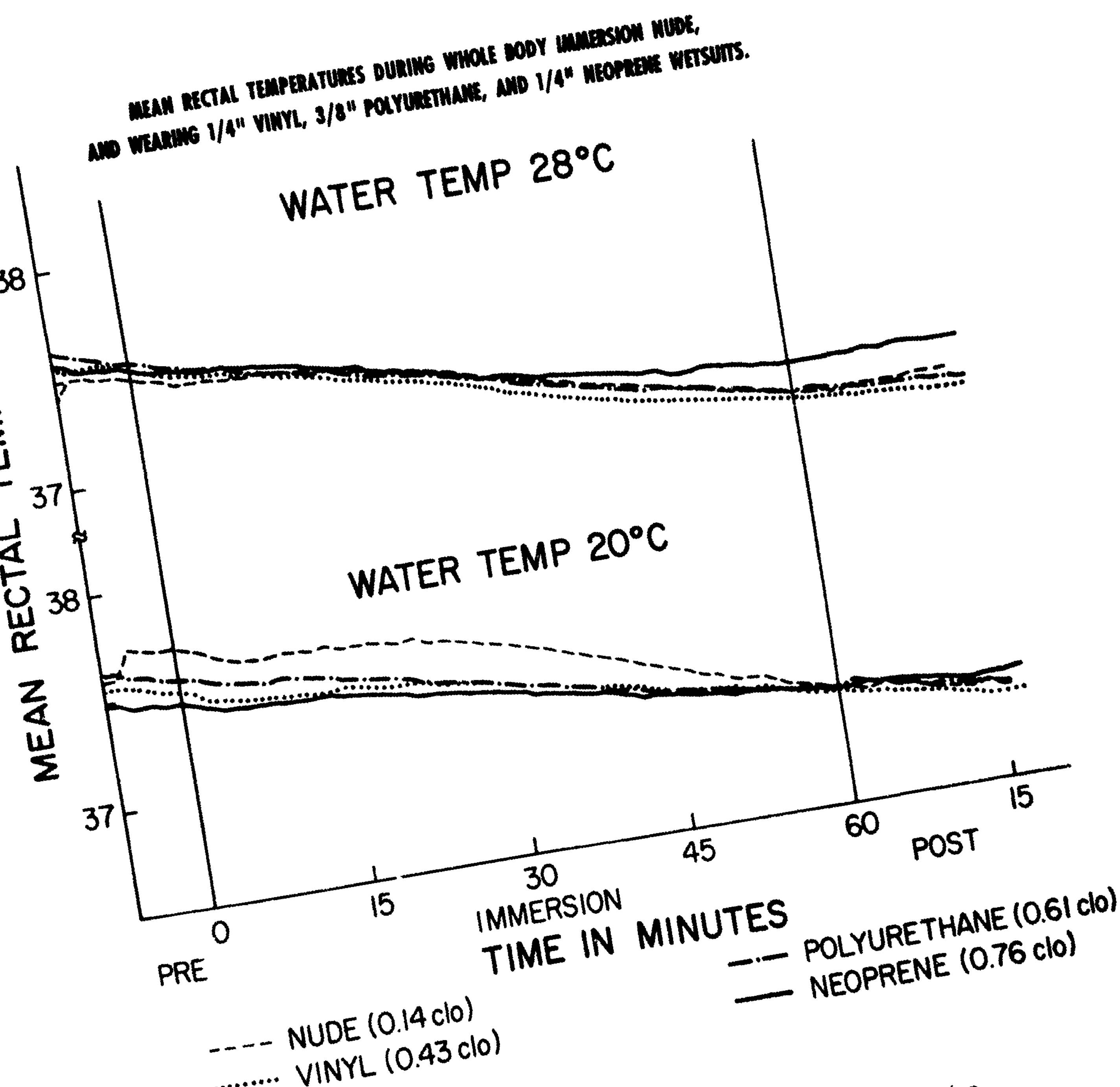

Figure 2. Mean Rectal Temperatures During Whole Body Immersion Nude, And Wearing 1/4" Vinyl, 3/8" Polyurethane, And 1/4" Neoprene Wetsuits.

MEAN METABOLIC RATES DURING WHOLE BODY IMMERSION; NUDE, AND WEARING 1/4" VINYL, 3/8" POLYURETHANE AND 1/4" NEOPRENE WETSUITS.

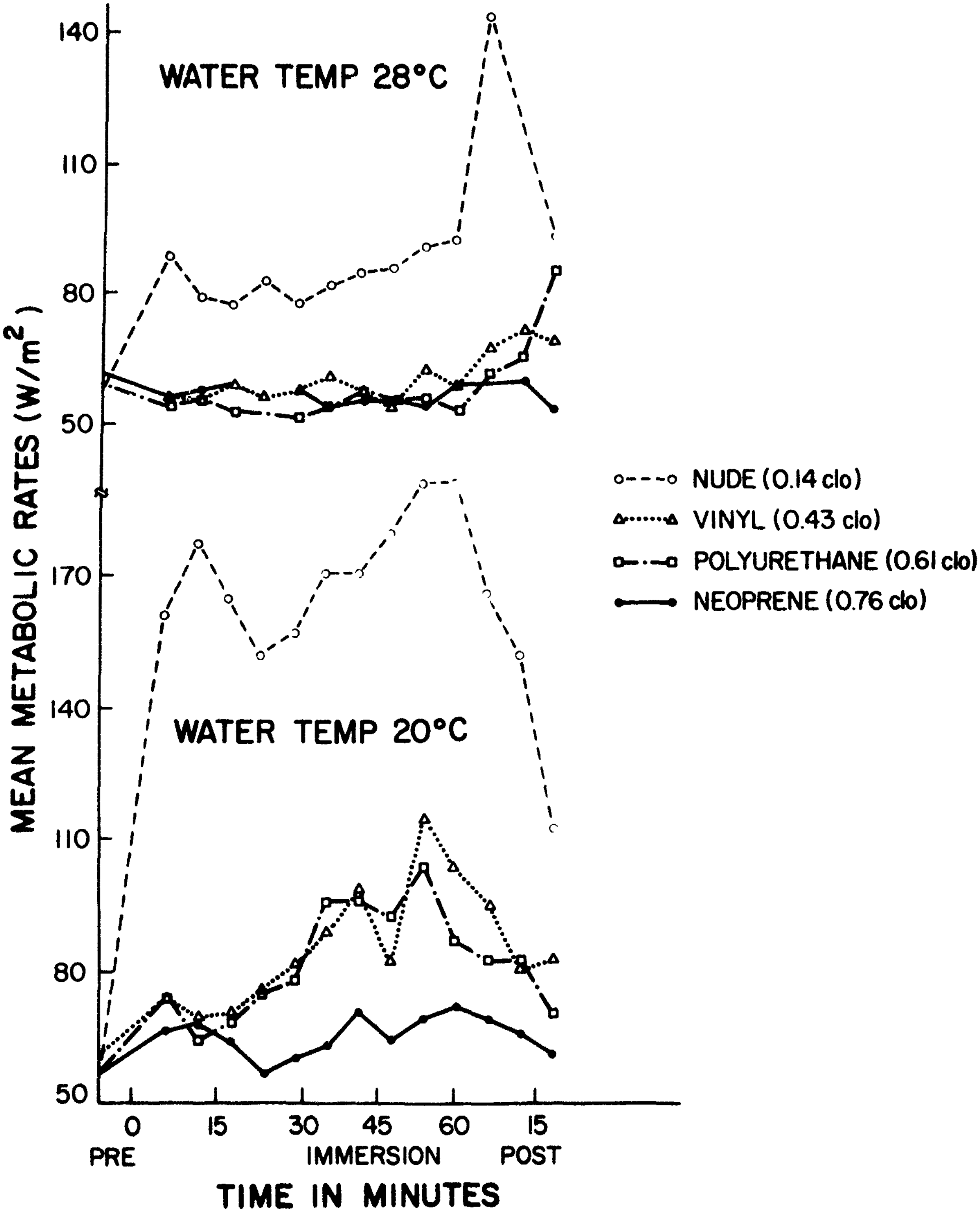

Figure 3. Mean Metabolic Rates During Whole Body Immersion; Nude, And Wearing 1/4" Vinyl, 3/8" Polyurethane And 1/4" Neoprene Wetsuits.

MEAN SURFACE HEAT LOSS* DURING WHOLE BODY IMMERSION; NUDE, AND WEARING 1/4" VINYL 3/8" POLYURETHANE AND 1/4" NEOPRENE WETSUITS.

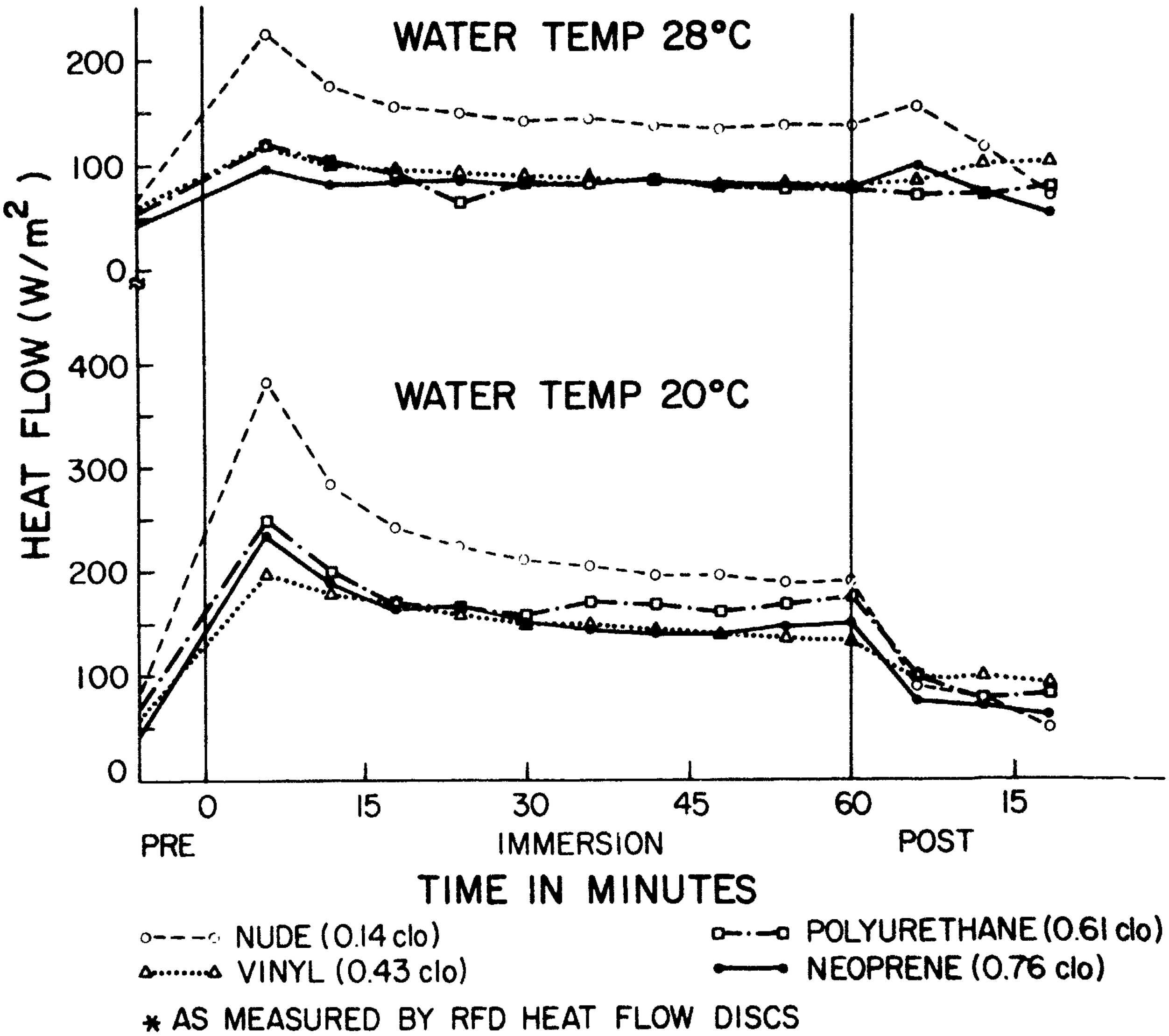

Figure 4. Mean Surface Heat Loss* During Whole Body Immersion; Nude, And Wearing 1/4" Vinyl, 3/8" Polyurethane And 1/4" Neoprene Wetsuits.

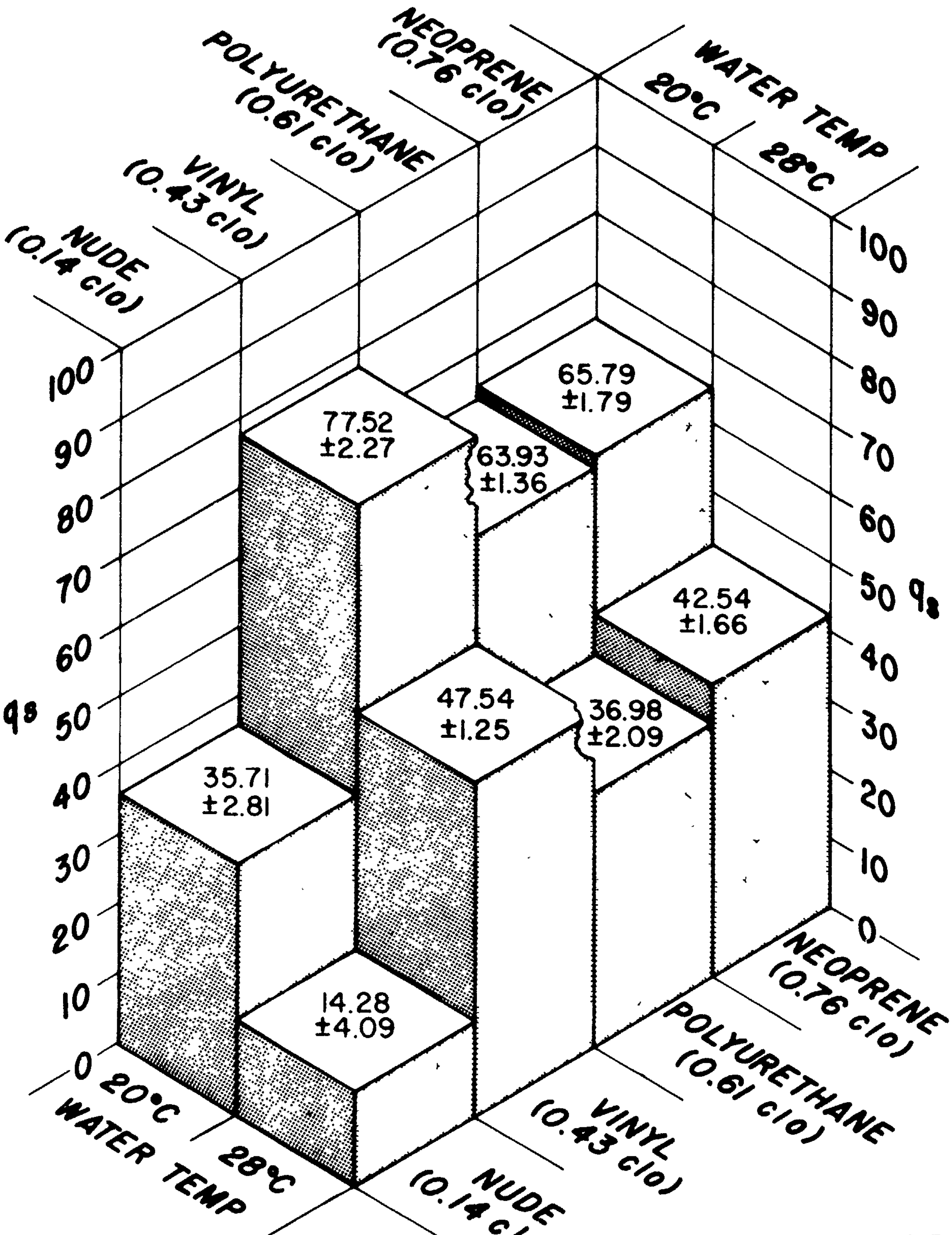

Figure 5. Means + S.E.

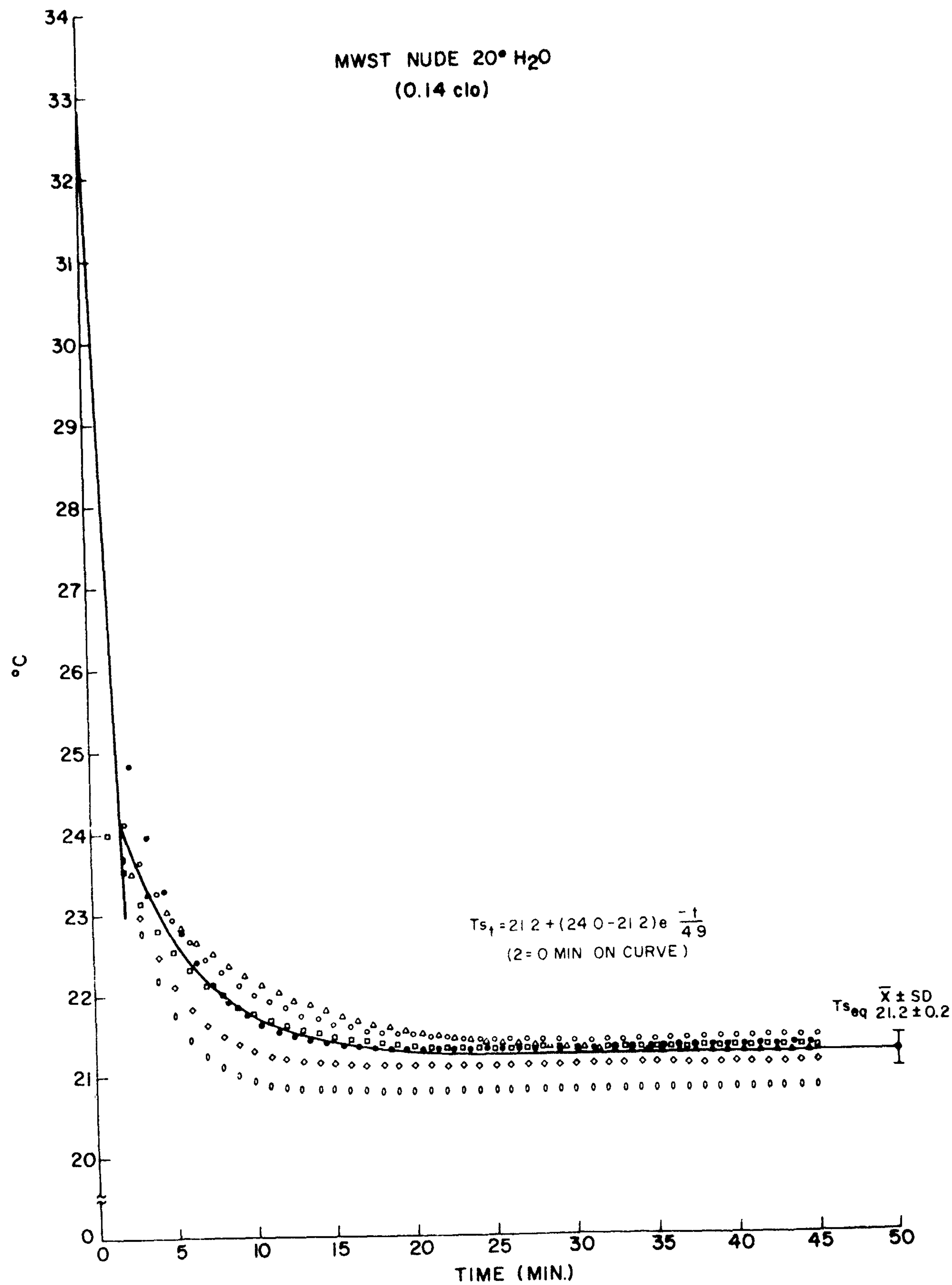

Figure 6. MWST Nude 20° H_2O (0.14 clo).

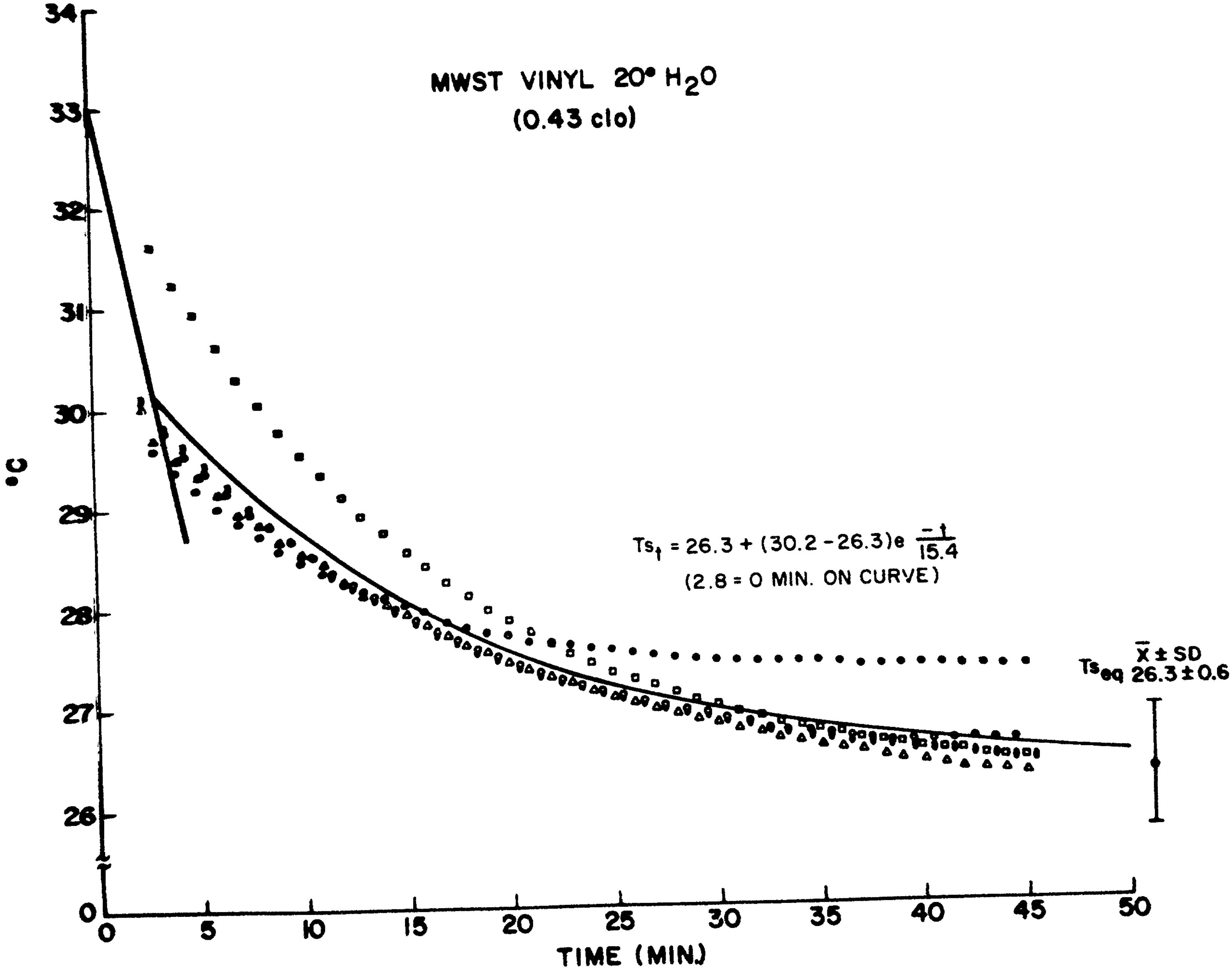

Figure 7. MWST Vinyl 20° H_2O (0.43 clo).

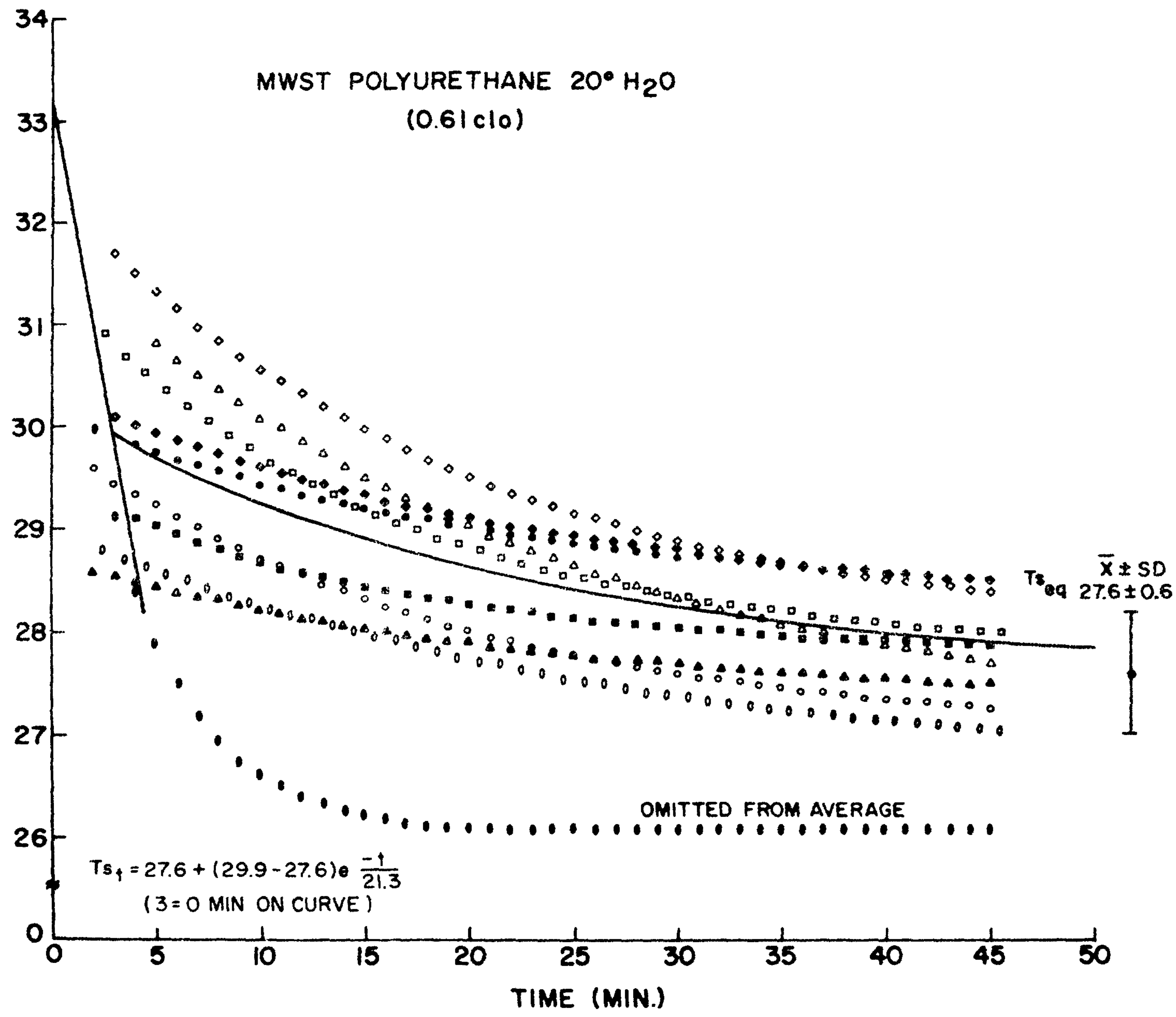

Figure 8. MWST Polyurethane 20° H_2O (0.61 clo).

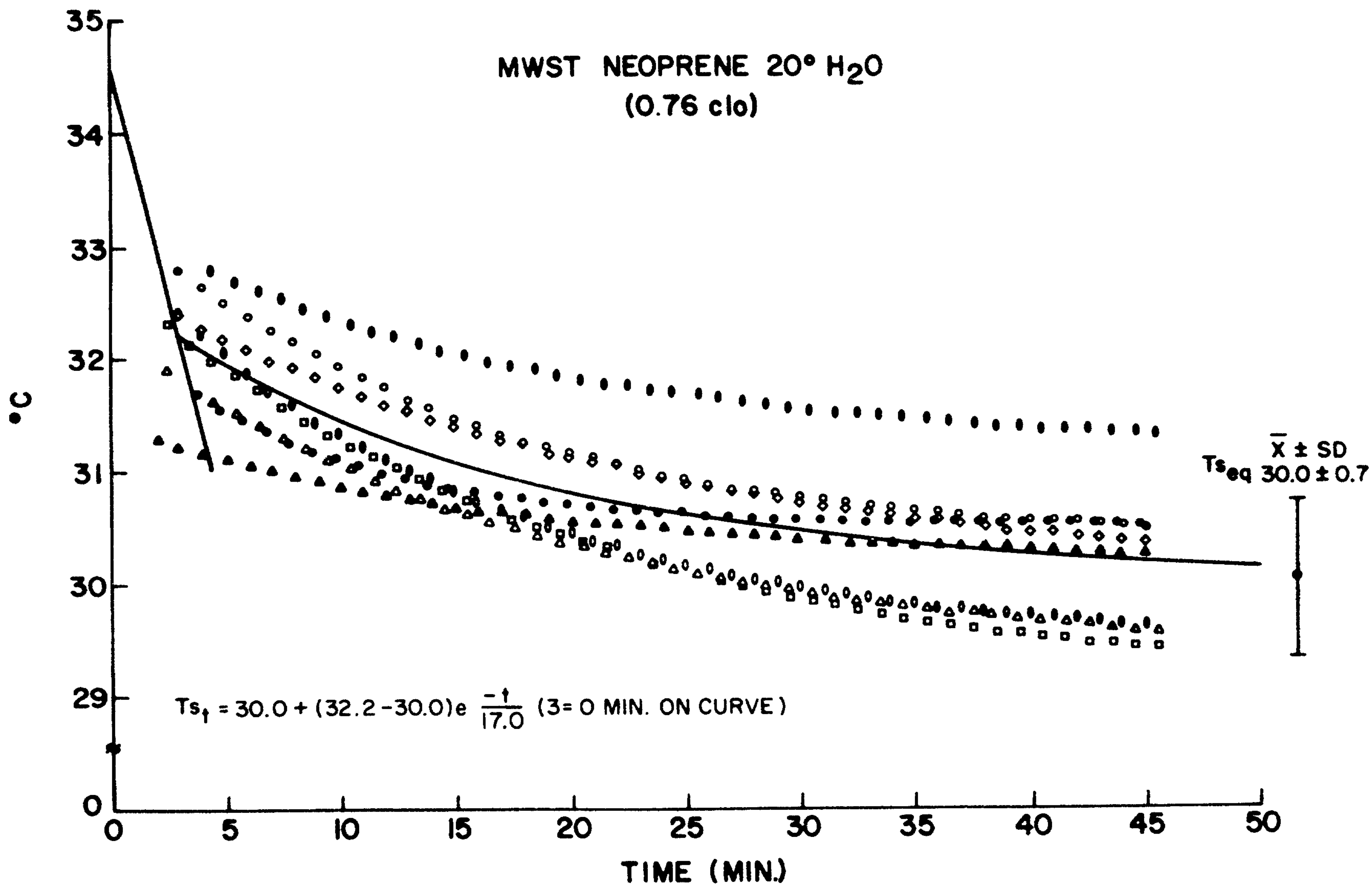

Figure 9. MWST Neoprene 20° H_2O (0.76 clo).

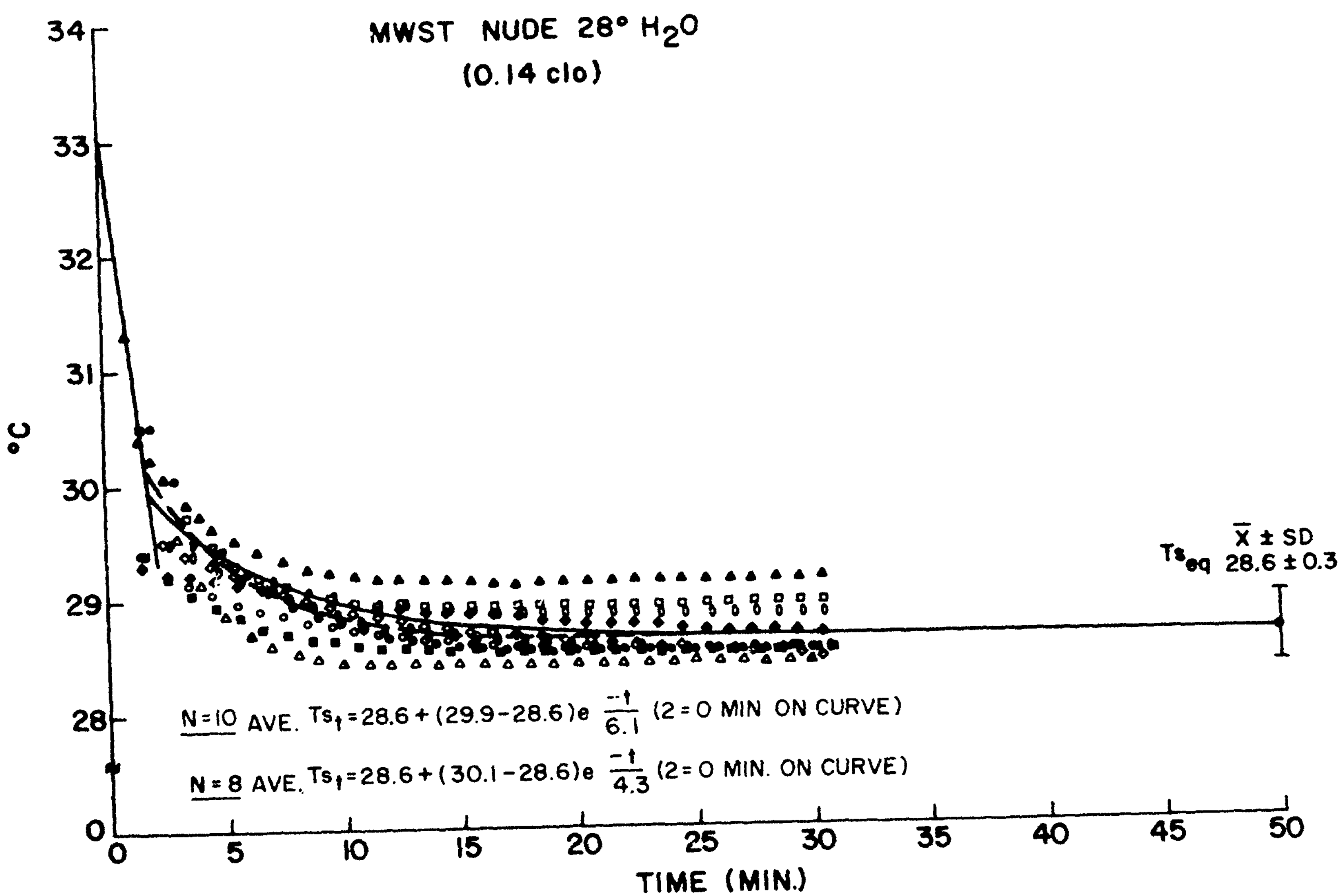

Figure 10. MWST Nude 28° H_2O (0.14 clo).

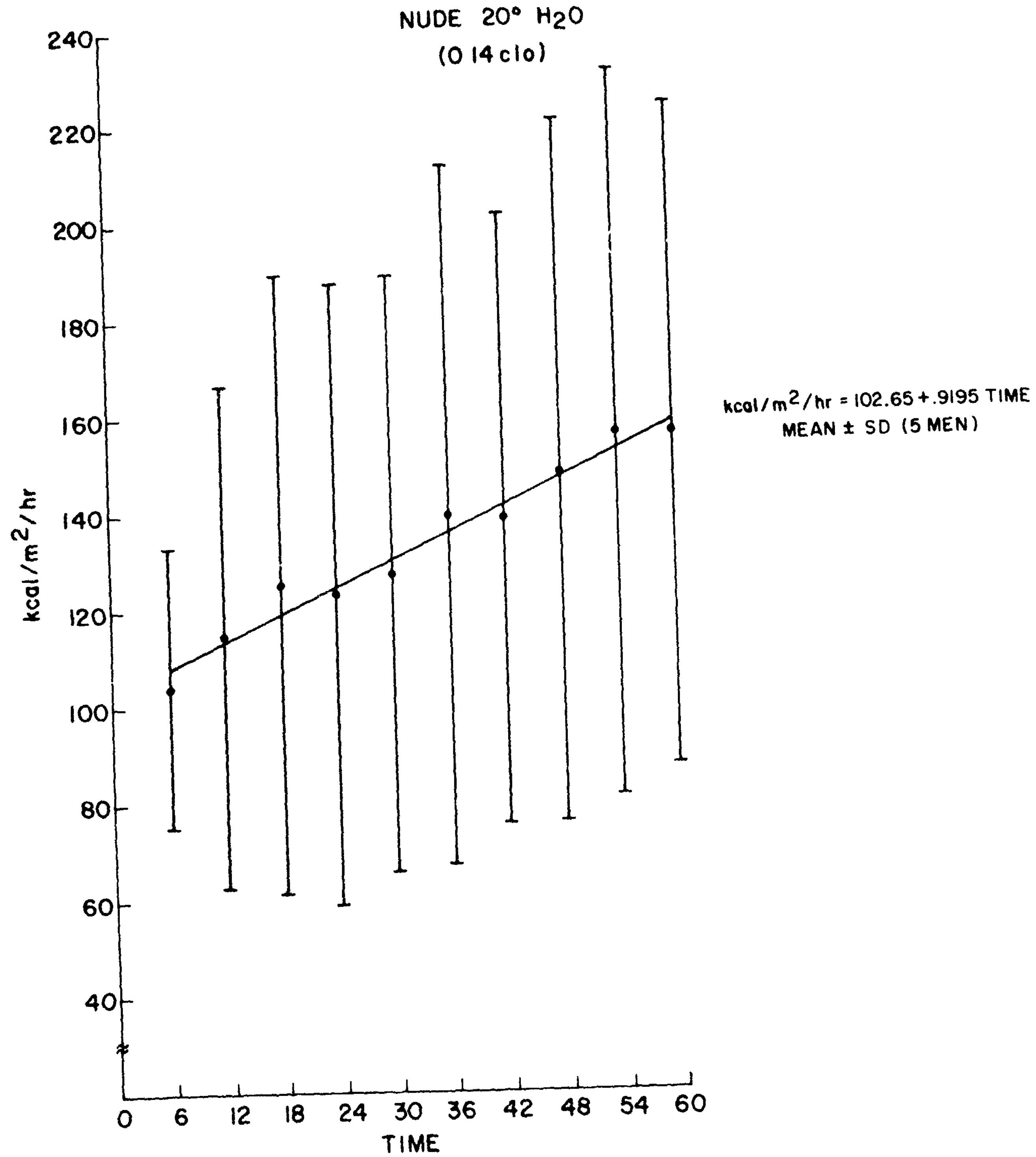

Figure 11. Nude 20° H_2O (0.14 clo).

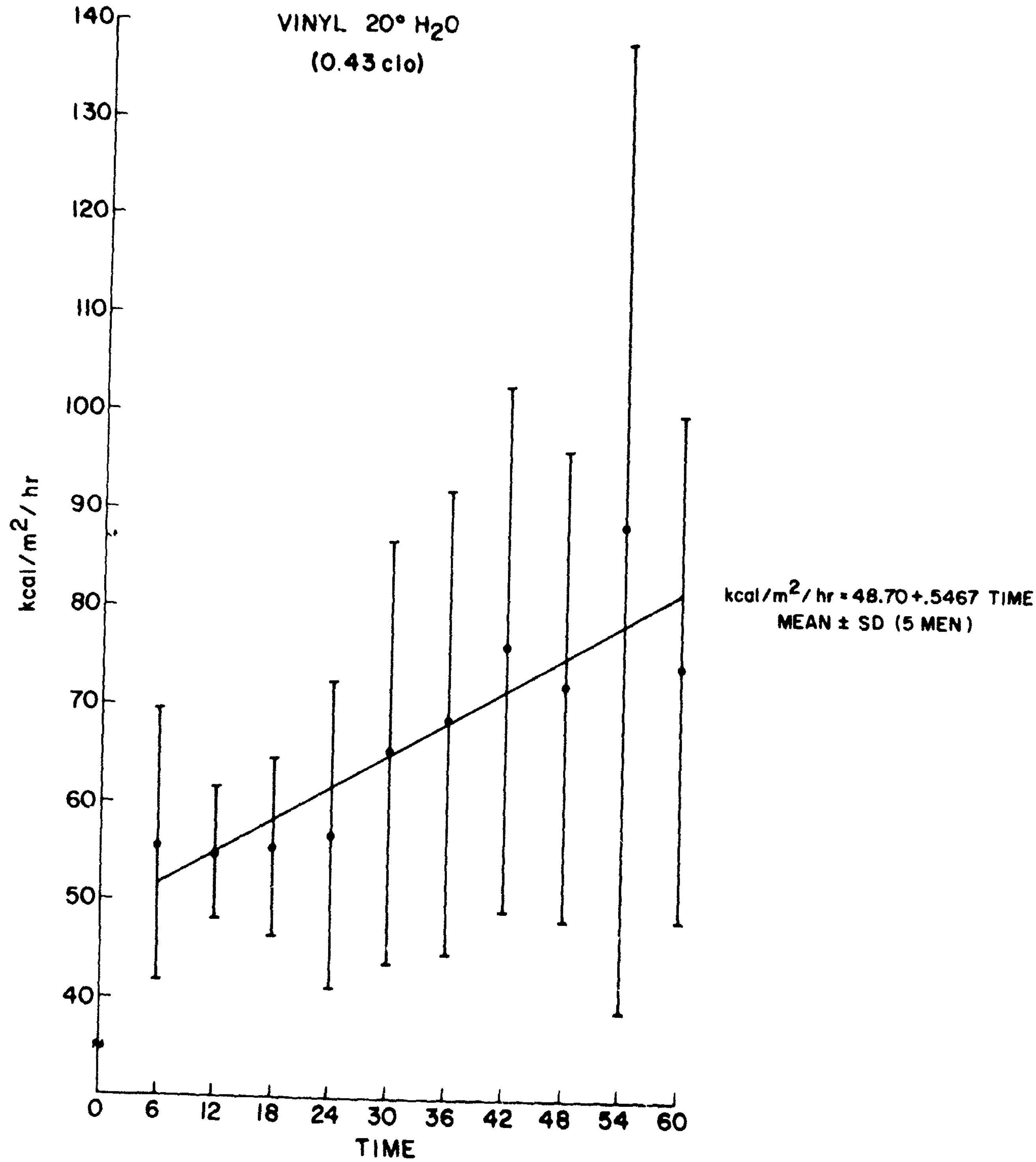

Figure 12. Vinyl 20° H_2O (0.43 clo).

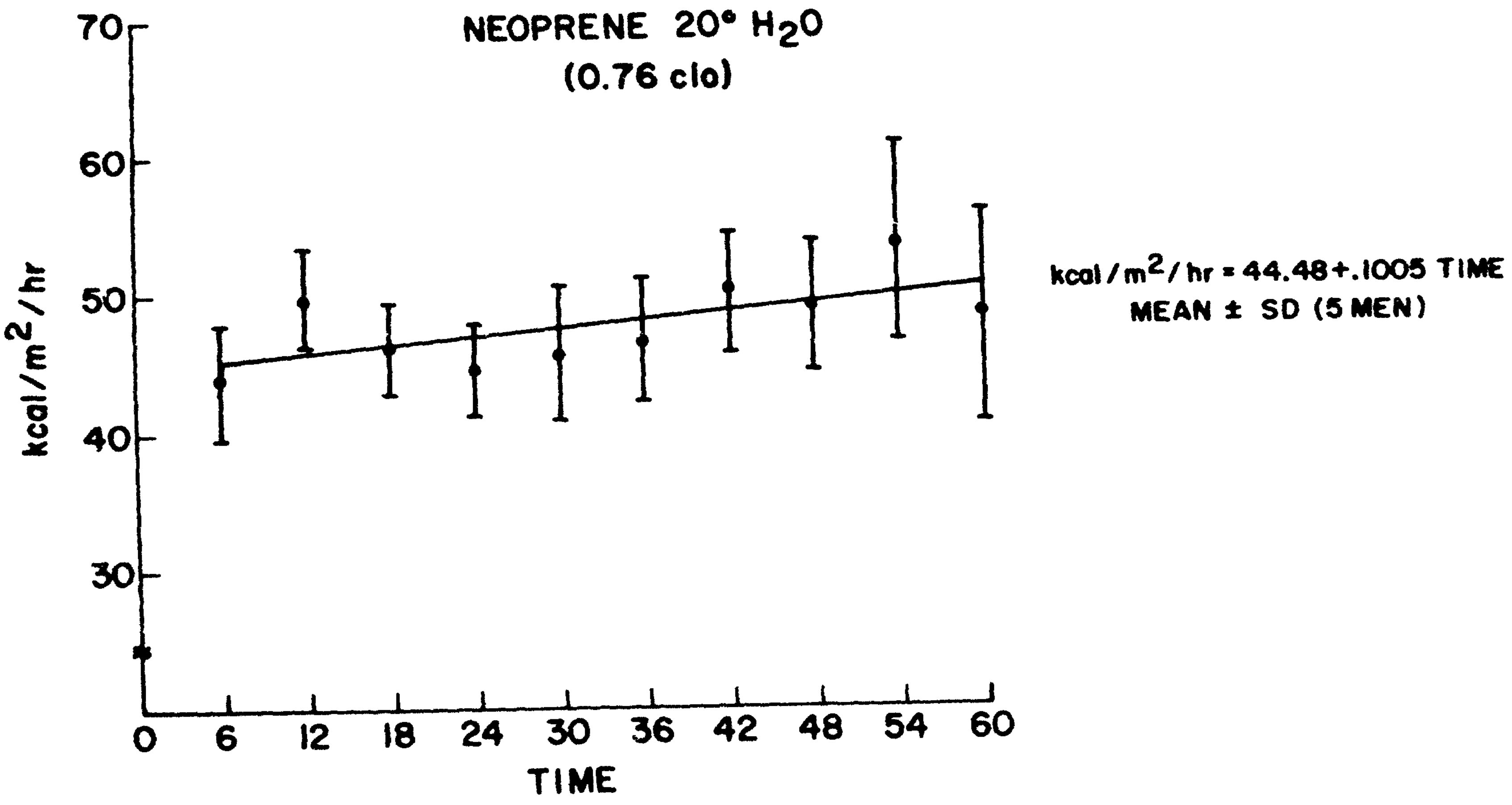

Figure 13. Neoprene 20^{o} H_2O (0.76 clo).

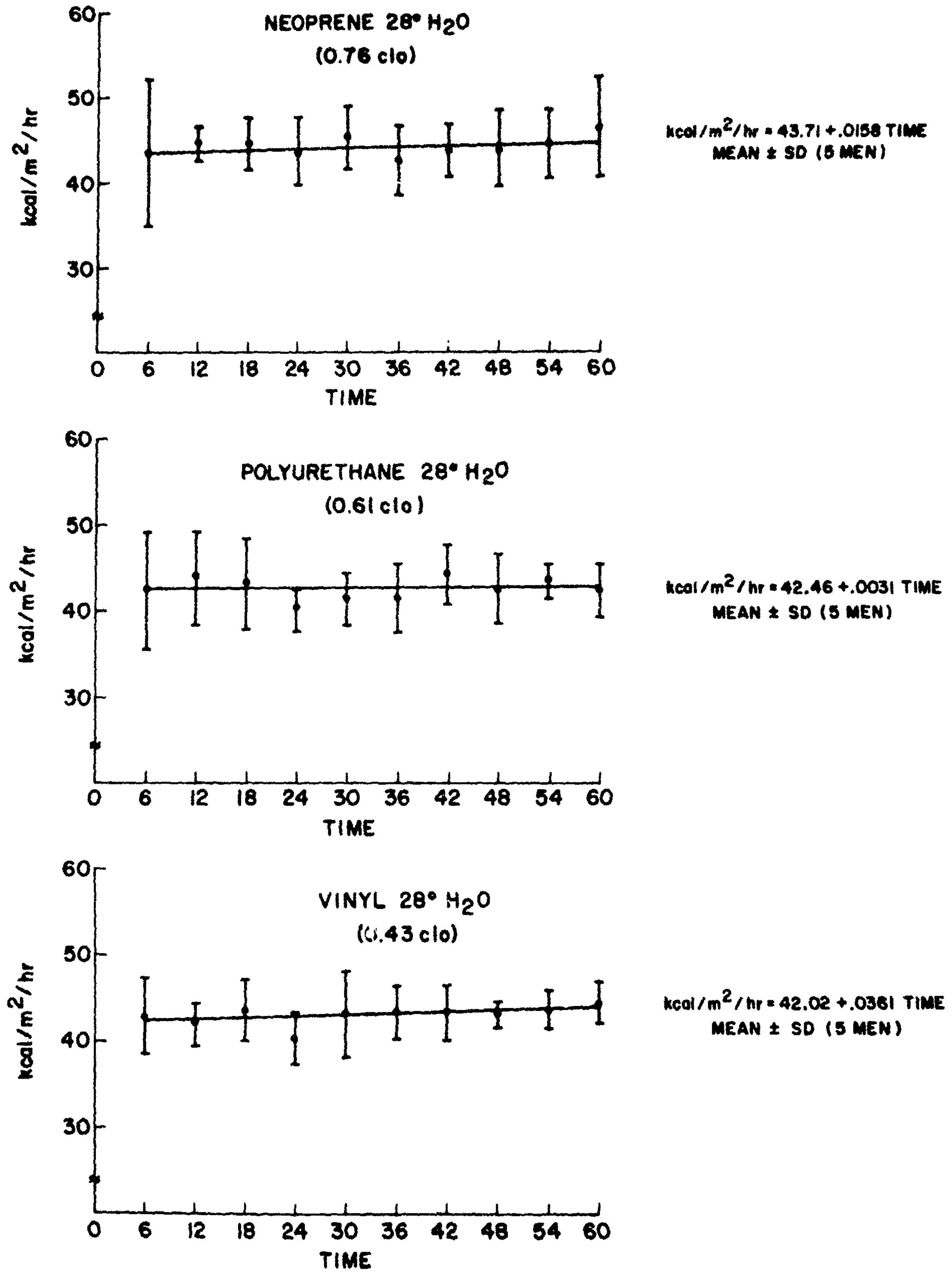

Figure 14. Neoprene 28^{o} H_2O (0.76 clo); Polyurethane 28^{o} H_2O (0.61 clo); Vinyl 28^{o} H_2O (0.43 clo).

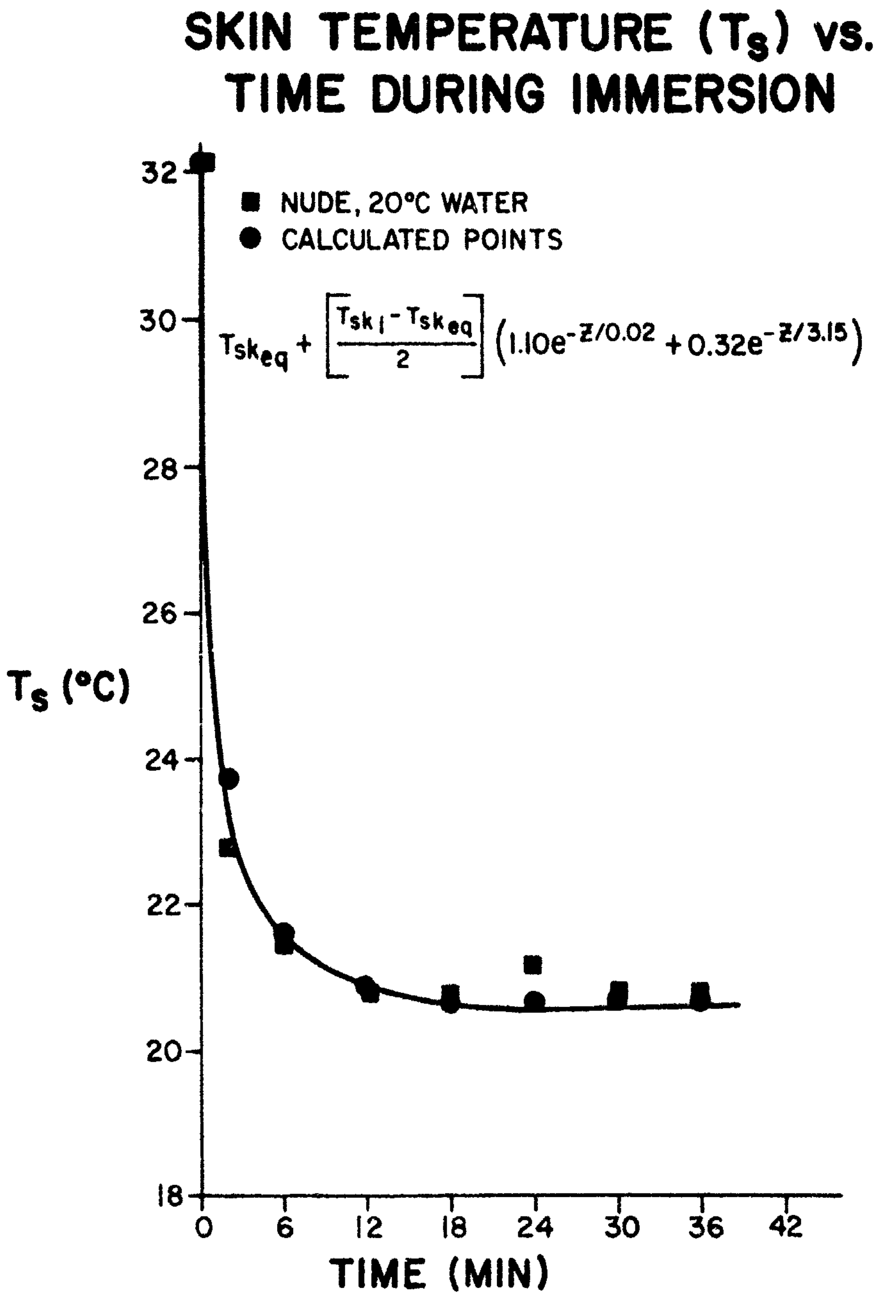

Figure 15. Skin Temperature (T_S) Vs. Time During Immersion.

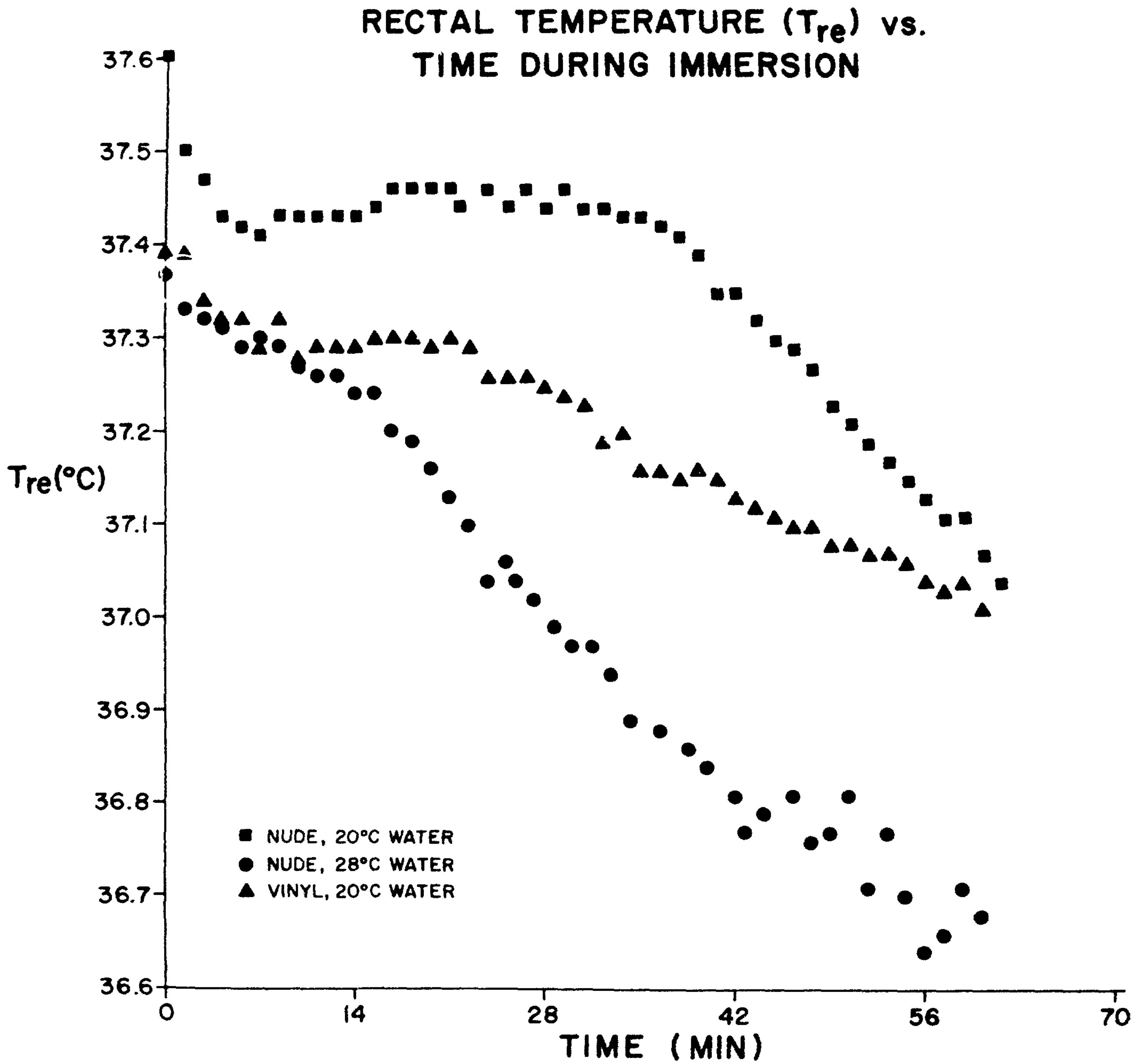

Figure 16. Rectal Temperature (T_{re}) Vs. Time During Immersion.

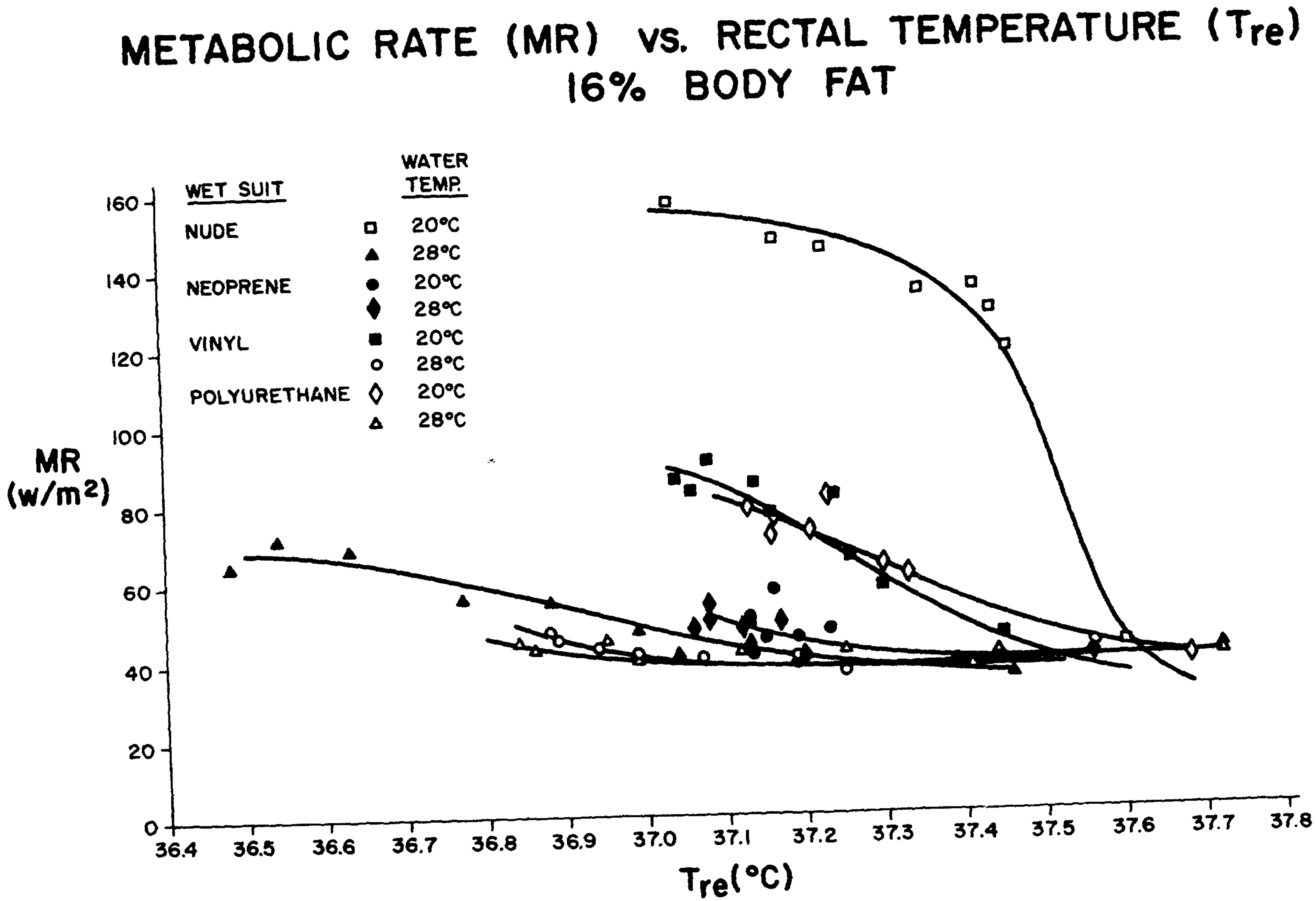

Figure 17. Metabolic Rate (MR) Vs. Rectal Temperature (T_{re})
16% Body Fat.

METABOLIC RATE (MR) VS. RECTAL TEMPERATURE (T_{re})
16% BODY FAT

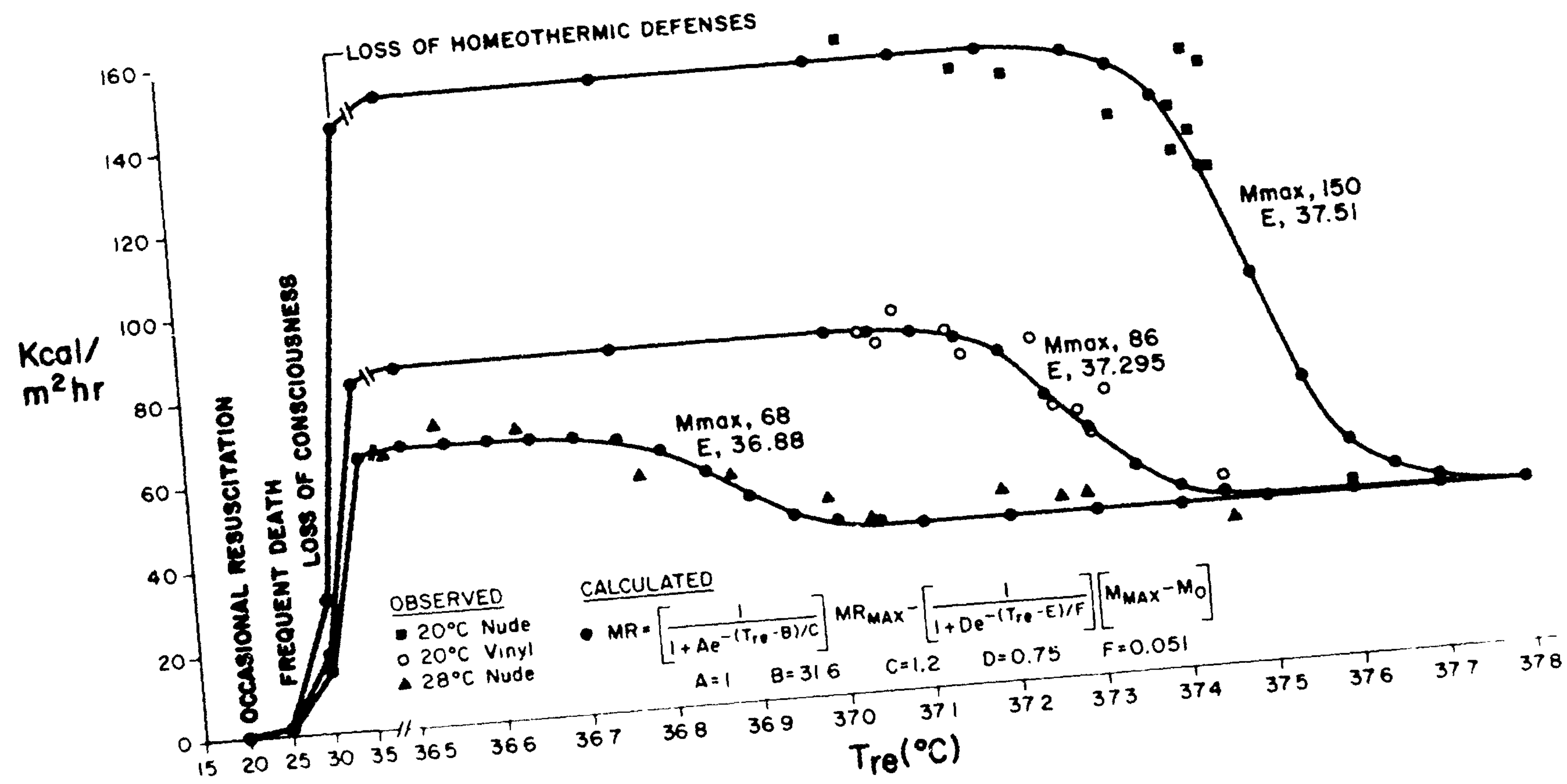

Figure 18. Metabolic Rate (MR) Vs. Rectal Temperature (T_{re}) 16% Body Fat.

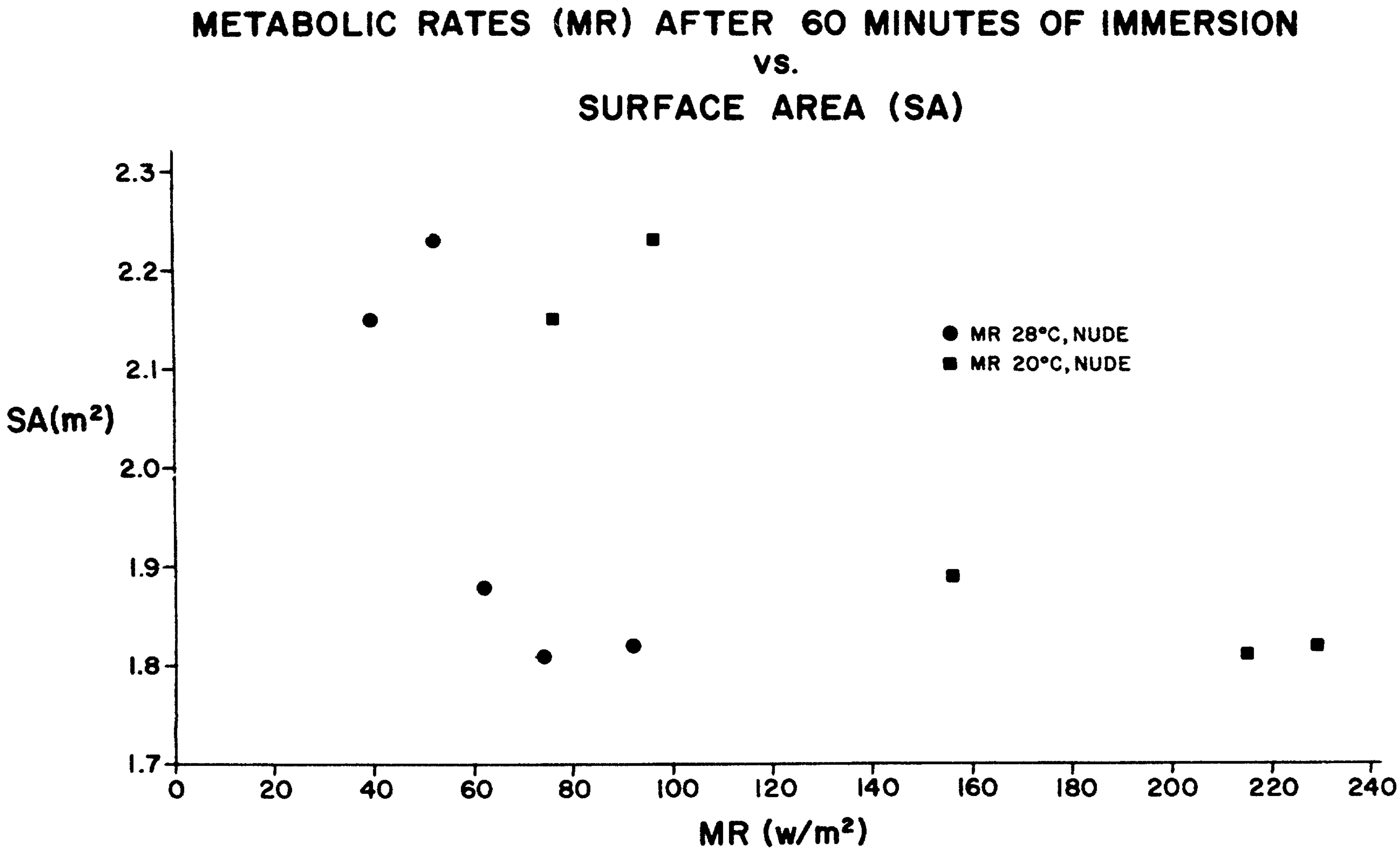

Figure 19. Metabolic Rates (MR) After 60 Minutes Of Immersion Vs. Surface Area (SA).

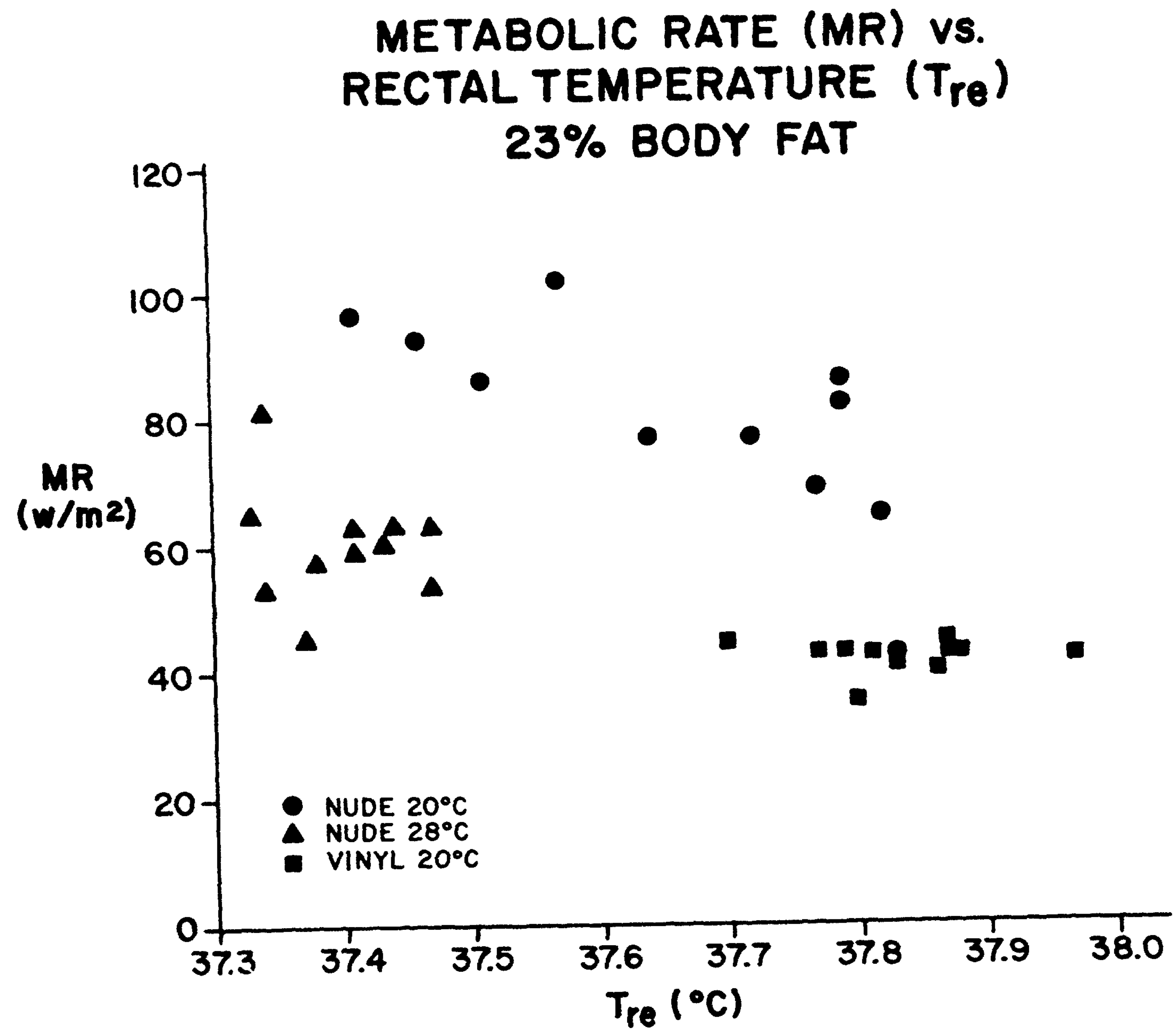

Figure 20. Metabolic Rate (MR) Vs. Rectal Temperature (T_{re})
23% Body Fat.

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